Regional Operational Plan CF.3A.2014.03

2014–2016 Kuskokwim River Chinook Salmon Mark–Recapture

by

Zachary W. Liller

March 2013

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

REGIONAL OPERATIONAL PLAN CF.3A.2014.03

2014–2016 KUSKOKWIM RIVER CHINOOK SALMON MARK–RECAPTURE

by

Zachary W. Liller

Alaska Department of Fish and Game, Commercial Fish Division, Anchorage

Alaska Department of Fish and Game
Division of Commercial Fisheries

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Zachary W. Liller,
Alaska Department of Fish and Game, Commercial Fish Division,
333 Raspberry Rd.
Anchorage, AK. 99518

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SIGNATURE/TITLE PAGE

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Approval

Title	Name	Signature	Date
Project leader	Zachary Liller		3/17/14
Area Biologist	Kevin Schaberg		3/17/14
Biometrician	Hamachan Hamazaki		3/17/14
Research Coordinator	Jan Conitz		3-17-2014
Regional Supervisor	John Linderman		3/21/14

Chinook Salmon Research Initiative Approval

Title	Name	Signature	Date
Fish and Game Coordinator	Ed Jones		3-25-14
Fisheries Scientist	Robert Clark		3/25/14
Fisheries Scientist	Eric Volk		3-26-14

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

Appendix **Page**

PURPOSE

The Kuskokwim River is 1 of 12 indicator stocks chosen by ADF&G, and assessment of total adult return is a significant component to understanding Chinook salmon production. Region III Commercial Fisheries plans to conduct a mark-recapture study to estimate abundance of Chinook salmon in the middle and upper Kuskokwim River. The middle and upper Kuskokwim River abundance is necessary component to reconstruct total return on an annual basis. Other components are either available, or are incorporated in additional planned operations with the intent of producing total return estimates.

Kuskokwim River Chinook salmon are managed according to the Kuskokwim River Salmon Management Plan to achieve escapements within the drainagewide escapement goal range. Evaluation of the drainage wide goal requires annually updating a statistical model that uses a previously defined relationship between total abundance and indices of abundance from a range of monitoring projects. To ensure adequate assessment, it is necessary that the run reconstruction model is scaled appropriately. Currently, the run reconstruction model is scaled using estimates from 2002–2007, corresponding to average and record high returns. More recent year returns of Chinook salmon have been below average, and years 2010–2012 are the lowest on record. Independent estimates of total abundance from 2014–2016 are needed to evaluate model scaling, and if necessary would be used to rescale the model for improved assessment. The previously used and proven method for estimating total run size of Chinook salmon requires conducting a large-scale mark–recapture study to estimate abundance upriver from Birch Tree Crossing.

BACKGROUND

From 2002–2006, Division of Sport Fisheries attempted to estimate adult Kuskokwim River Chinook salmon abundance upriver of kilometer (rkm) 306 (a point immediately downriver from the community of Aniak) using a Petersen two-sample mark–recapture experimental design (Stuby 2007). A combination of drift gillnets and fish wheels were used to capture Chinook salmon along both banks of the mainstem Kuskokwim River near the community of Kalskag (rkm 263). A portion of the daily catch was marked using radio tags as a primary mark and external spaghetti tags as a secondary mark. Fish were tagged following a daily schedule based on historical run timing and a weekly schedule that allocated tags to large (>650mm) and small (<650mm) Chinook salmon. The goal was to distribute tags proportional to run strength, size composition, and bank of migration, with the overall goal of ensuring that all upriver spawning stocks have an equal probability of being marked. Only those tagged fish that migrated past a stationary telemetry tower located near Aniak (rkm 306) were considered part of the marked population. Recapture sampling was conducted at 4 upriver weirs located on the George (rkm 453), Kogrukluk (rkm 710), Tatlawiksuk (rkm 568), and Takotna Rivers (rkm 835). Only those fish that were observed passing through the weirs constituted the second sampling event (i.e., estimates of missed passage were not used). Tag recaptures were determined using stationary tracking towers and aerial surveys upriver of the weirs. Only those tagged fish that passed when the weirs were operational were counted.

During the first 4 years of study (2002–2005), radio-tagged Chinook salmon bound for the Aniak River demonstrated bank orientation at the marking sites, in contrast with salmon migrating to other spawning tributaries (Stuby 2003, 2004, 2005, and 2006). During those early years, second event recapture sampling was not done in the Aniak River, and it was not possible to assess whether Aniak fish were marked in similar proportion to other stocks. As a result, Aniak River

Chinook salmon were excluded from abundance estimation calculations, and the resulting abundance estimates were germane to all waters upstream from the mouth of the Aniak River.

In 2006, Division of Commercial Fisheries, in cooperation with Kuskokwim Native Association, installed a weir on the Salmon River, a headwater tributary of the Aniak River, for the purpose of recapture sampling during the final year of abundance estimation (Stuby 2007, Schaberg et al. 2012). For the first time, marked and unmarked ratios of Chinook salmon from the Aniak River could be compared to those of the George, Tatlawiksuk, Kogrukluk and Takotna Rivers. Despite bank orientation, radio tags were found to be distributed proportionally among upriver spawning stocks. Based on that finding and other diagnostic tests, an unstratified Petersen estimator was used to estimate abundance of Chinook salmon upriver from the tag site.

Division of Commercial Fisheries, with cooperation with Kuskokwim Native Association, continued the mark–recapture study for an additional year in 2007. Techniques were similar to those used in the 2002–2006 studies, including continued operation of the Salmon River weir (Schaberg et al 2012). However, in that year, the Aniak telemetry tower was discontinued due to problems with that location, and it was replaced with a tower located downriver near Birch Tree Crossing (rkm 270). Estimates of missed weir passage were calculated and considered part of the recapture sample event. This was done because Division of Commercial fisheries has established methods for estimating missed passage; and, by including estimated passage, radio tagged fish that were known to pass during periods when the weirs did not operate could be included in the study. No significant bias was detected in 2007 and abundance upriver of Birch Tree Crossing was estimated using an unstratified Petersen estimator as in the previous year.

Beginning in 2007, Division of Commercial Fisheries developed a statistical model to reconstruct a historical time series of total annual abundance of Kuskokwim River Chinook salmon (Bue et al. 2012). The model relies on defined relationships between indices of salmon abundance from weirs, aerial surveys, and harvest, and total population size. The model requires some independent annual estimates of total abundance for scaling purposes. These independent estimates were reconstructed for years 2002–2007 by combining estimates from mark–recapture studies, weir counts, habitat production models, and harvest. However, published mark–recapture results were not directly comparable, because the 2002–2005 estimates did not include the Aniak River and the 2007 estimates used a modified study design. In order to address these issues, all data from 2002–2006 was reanalyzed using the study design implemented in 2007. New information from the Salmon River weir in 2006 and 2007 provided reasonable confidence to include Aniak River fish in all estimates (Table 1; Schaberg et al. 2012). Using these updated mark–recapture data as input, the full run reconstruction was completed and estimates of total annual abundance were calculated for 1976–2011 (Figure 1; Bue et al. 2012).

This series of reconstructed total abundance estimates was used in conjunction with age-composition data to conduct a spawner recruit analysis, leading to a recommended drainagewide escapement goal for Kuskokwim River Chinook salmon (Hamazaki et al. 2012). This recommended goal of 65,000–120,000 Chinook salmon was presented to the Alaska Board of Fisheries during the 2013 cycle (Conitz et al. 2012) and incorporated into the Kuskokwim River Salmon Management Plan (5 AAC 07.365) for the 2013 salmon season.

By design, evaluation of the whole river escapement goal is tied to and scaled by the run reconstruction model. Annual assessment of escapement is achieved by updating the run reconstruction model with new index data from weirs, aerial surveys, and harvest to estimate total escapement. This assessment assumes that the model is scaled correctly (Bue et al. 2008 and 2012). Currently the run reconstruction model is scaled using estimates from 2002–2007, years with moderate and record high returns. More recent year returns of Chinook salmon have been below average, and 2010–2012 are the lowest runs on record (Figure 1). Independent estimates of total abundance from more recent years, and in particular, years with lower abundance values, are needed to evaluate model scaling, and if necessary would be used to rescale the model for improved assessment. The previously used and proven method for estimating total run size of Chinook salmon involves repeating the large-scale mark–recapture study to estimate abundance upriver from Birch Tree Crossing.

OBJECTIVE

Estimate the abundance of adult Chinook salmon in the Kuskokwim River for all waters upriver of Birch Tree Crossing (river kilometer 294), .such that the bounds of the 95% confidence interval are within ±25% of the estimated abundance.

METHODS

This project will operate for 3 years: 2014–2016. The following methods are planned for the 2014 season.

OVERVIEW OF STUDY DESIGN

In 2014, the abundance of adult Kuskokwim River Chinook salmon upriver of Birch Tree Crossing will be estimated using two-sample Petersen mark–recapture and radio telemetry methods, designed to satisfy the following assumptions:

1. the population is closed during the experiment (adult Chinook salmon do not enter the population via growth or immigration, or leave the population via death or emigration);
2. all adult Chinook salmon bound for waters upriver of Birch Tree Crossing have a similar probability of capture in the first event or in the second event, or marked and unmarked fish mix completely between events;
3. marking of adult Chinook salmon will not affect the probability of capture in the second event;
4. all marked Chinook salmon will be identifiable during the second event; and,
5. all marked Chinook salmon will be reported when recovered in the second event.

Attempts will be made to capture Chinook salmon and distribute radio tags over the span of the run, in proportion to run strength, size composition, and bank of migration, with the overall goal of ensuring that all upriver spawning stocks have an equal probability of being marked. The initial capture event will be conducted using drift gillnets and bank-mounted fish wheels operated throughout the run. The primary mark will be an esophageal radio tag, and a t-bar anchor tag will be given as a secondary mark. Only those fish that retain their radio tags and are known to migrate and remain upriver of Birch Tree Crossing will constitute the first sample.

Tagged fish will be tracked using a combination of stationary and aerial techniques. A total of 17 stationary tracking towers will be positioned along the course of the mainstem Kuskokwim River and in select spawning tributaries. Two aerial survey flights will be flown along the mainstem Kuskokwim River at the end of season.

Weirs operated on 4 spawning tributaries upriver from the tagging site will be used for recapture sampling. Crews comprised of ADFG/CFD and Kuskokwim Native Association staff, will be stationed at each weir location to count the passage of all Chinook salmon. Estimates of missed passage will be made for times when the weir is not operational. A radio-tracking station will be positioned upstream from each of the four weirs to record the passage of marked fish. The second sample will be the sum of all Chinook salmon estimated through the 4 weirs, and the number of marked fish will be the sum of all the radio tagged fish that swim through the weirs.

A volunteer tag lottery will be conducted to encourage reporting of tagged fish harvested in the subsistence fishery by local fishermen upriver of the tag site. The lottery will be advertised using mailers sent to rural business, and with printed labels on all tags.

The study design ensures that the fate of each tagged fish can be assigned to one of the following fates necessary for testing model assumptions and abundance estimation:

1. a fish that survives tagging and handling, continued upriver migration, and remained upriver of Birch Tree Crossing during the entire study period;
2. a fish that travels past one of the 4 recapture weirs located on the George, Tatlawiksuk, Kogrukluk, or Takotna rivers;
3. a fish that does not survive tagging and handling, does not continue upriver migration, or does not remain upriver of Birch Tree Crossing during the entire study period.
4. a fish that travels to an unmonitored tributary upriver of Birch Tree Crossing;
5. a fish that remains upriver of Birch Tree Crossing, was not harvested, but died prior to entering a tributary;
6. a fish that migrated upriver of Birch Tree Crossing but was harvested.

The design will ensure that sample sizes are adequate to meet the objective for precision and to perform reliable diagnostic tests. Sufficient data will be collected to identify and correct for outmigration and mortality of tagged fish from the study area (violation of Assumption 1), heterogeneous capture probabilities (violations of Assumption 2), and tag loss (violations of Assumption 4 and 5). Diagnostic tests are not available to evaluate effects of tagging on the behavior of marked fish (Assumption 3); rather, the experiment is designed to minimize the capture and handling stress, thereby avoiding potential bias.

Study Area

Estimates of abundance are germane to all waters upriver of Birch Tree Crossing located at rkm 294 (Figure 2). Due to the migratory nature of Chinook salmon, sampling and tracking efforts will encompass the entire watershed upriver of Birch Tree Crossing and the mainstem portion of the Kuskokwim River downriver to rkm 233.

Initial capture and tagging will occur from a remote field camp located at rkm 270 (Figure 2). This site was chosen because it is upriver from where all commercial and nearly 90% of subsistence harvest of Chinook salmon occurs. It is also downriver from majority of the Chinook salmon spawning tributaries. Informal surveys conducted near the tag site indicate a relatively shallow and uniform bottom profile, with average depth of about 4.5 m and maximum depth of about 10.5 m at a moderate river stage. The location is suitable for operations of drift gillnets and fish wheels. One fish wheel will be operated along each bank of the river. The north bank (river right) wheel will be placed approximately 0.8 km downriver from the camp site. The south bank (river left) wheel will be placed in one of two approximate locations: 1) 2.7 km upriver from the camp site or 2) directly across the channel from the north bank wheel. Fish wheel locations will be determined inseason after evaluating river bottom profile, water depth, and flow. Drift gillnet sites will be near the fish wheel locations (Figure 3).

A series of 17 stationary tracking towers will be located throughout the middle and upper portions of the Kuskokwim River drainage from rkm 233 to 863 (Figure 2). One tracking tower located at Birch Tree Crossing (rkm) demarks the lower boundary of the mark–recapture study area.

Weirs used for recapture sampling are located on the Salmon (rkm 404; Aniak River drainage) George (rkm 453), Kogrukluk (rkm 710; Holitna River drainage), and Tatlawiksuk (rkm 568) rivers (Figure 2). The array of weirs include north and south draining tributaries and account for approximately 15–20% of the total escapement of Chinook salmon upriver of Birch Tree Crossing, and are therefore considered to adequately represent the unmonitored escapement.

Evaluation of Assumptions

Assumption 1: This assumption will be violated because harvest of some fish will occur between events. However, we assume that marked and unmarked fish will be harvested at the same rate. Thus, provided there is no immigration of fish between events, the estimate will be unbiased with respect to the time and area of the first event (estimate of inriver abundance, not escapement). Sampling in both events will encompass the majority of the run, and any immigration of Chinook salmon past the capture sight prior to or after the marking event is assumed to be negligible. Furthermore, only those tagged fish that remain in the study throughout the duration of the operational period will be counted as part of the marked population.

Assumption 2: An unbiased estimate requires that one of the 3 conditions affecting capture probability must be met. The probabilities of individual salmon being captured during the second event, are effectively predetermined as 1 or 0 based on whether or not the individual is bound for a tributary with a weir, and are therefore not equal among all salmon in the experiment. Also, mixing between events generally does not occur. Therefore, robust estimation is dependent on maintaining a uniform probability of marking among all spawning stocks during first sampling event.

Equal probability of capture will be also evaluated by size, sex, and time. Procedures for evaluating bias are described in Appendix A1 and A2. Significant results from these tests are indicative of potential sampling biases which in some cases can be addressed by censoring data, stratification, or alternative models (e.g., Darroch 1961, Bromaghin et al. 2010). In some cases, no remedial measures will be apparent and simulation studies may be required to evaluate the potential bias for abundance estimation.

Assumption 3: There is no explicit test for this assumption; however, the study is designed to minimize behavioral effects. Specific measures include: minimizing holding time (Liller et al. 2011); only tagging healthy fish; using appropriately sized tags (Winter 1983); and censoring fish that do not continue upriver migration after tagging and fish that leave the study area during the operational period.

Assumptions 4 and 5: All radio tagged fish will be given a secondary external tag. Tag recovery data from weirs and telemetry will be used to estimate the percent of fish that lost their radio tag prior to reaching the recapture site and total tag recaptures will be estimated.

FIRST EVENT SAMPLING METHODS

Efforts to capture Chinook salmon for marking will be conducted 6 days per week beginning June 5 and will continue until approximately July 31. Operational dates provide a reasonable assurance that all temporal components of the run have a non-zero probability of capture during the first event. Based on prior year data, less than 2% of the total season catch occurred prior to July 5 and less than 10% (mean: 4%) occurred after July 31 (Appendix B1). Tagging operations will continue into early August if daily catch rates warrant the extra effort.

Drift gillnets, fished from a 20ft riverboat, will be used to target medium to large size adult Chinook salmon that migrate throughout all spatial components of the river channel. Gillnets will be constructed of multi-fiber mono, mesh sizes will be 7.5 in and 8.0 in stretched, 29 meshes deep (approximately 6.1m), and. All nets will be hung at a 2:1 ratio to a finished length of 25 fathoms (45.7 m). The depth of nets is adequate to ensure that majority of the water column is sampled, across the range of expected water levels, regardless of where the net is fished along the horizontal transect of the river.

Bank-mounted fish wheels will be used to supplement drift gillnet catches and target small Chinook salmon that tend to migrate in shallow waters. Fish wheels will consist of 3 baskets measuring 2.4x3.0 m (length x width) constructed of aluminum, covered with 3 in knotted webbing, and equipped with a plywood chute. A perforated plywood live box measuring 2.4x1.2x0.6 m (length x width x depth) will be attached to the offshore side of each wheel and used to hold fish between sampling events. A weir measuring approximately 5 m in length will be attached to the inshore side of each wheel and extend perpendicular to the bank. Wheels will generally be positioned to fish in water depths of 1–2 m, maintain 2–4 basket revolutions per minute, and minimize the distance between the basket and the substrate. Consistent fishing effort will be maintained by adjusting the distance from shore, vertical position of the baskets, and location.

Drift gillnets and fish wheels will be operated by a single 3-person crew, comprised of ADFG/CFD and Kuskokwim Native Association staff, alternating effort between capture gears. Fishing effort will occur between the hours of 0600 and 2400. The work day will be divided into three 4-hour strata, corresponding with times of expected elevated catch rates (Figure 4): 1) 0700–1100; 2) 1200–1600; and 3) 2100–2300 (Table 2). Fish wheels will operate continuously during each 4-hour stratum, for a total of 12hrs of fishing time per day. Fish wheel live boxes will be checked for presence of Chinook salmon every hour. Based on historic hourly catch rates during the peak of the run, we expect that all captured fish can be processed in approximately 15min (Figure 5). Drift gillnet fishing will be performed as crew transition between fish wheels. Drift gillnets will be fished for a total of 1.5 hrs of soak time per 4-hour stratum or until time expires for a maximum effort of 4.5 hrs per day. The drift zone will be sufficiently long to complete two adjacent 15 minute drifts, with the center of the zone determined by the location of the north bank fish wheel. The drift zone will consist of 3 fishing stations targeting those portions of the channel along both banks and the middle (Figure 3). Fishing effort and mesh size used will rotate among drift stations every shift, such that over a 6-day period all stations have been fished with equal effort. The starting zone and mesh size will follow a predefined schedule intended to ensure equal effort among stations (Table 3). When a Chinook salmon is captured in a drift gillnet, the net will be immediately retrieved into the boat.

Tagging and Handling Methods

Pulse encoded esophageal radio tags manufactured by Advanced Telemetry Systems (ATS) will be used as the primary mark. Radio tags will be programed with a duty cycle that renders the tag inert after 180 days of continuous operation – this eliminates potential confusion associated with using the same tag frequencies and pulse codes in future study years. A total of 10 frequencies with 100 codes per frequency yield 1,000 uniquely identifiable tags (Table 4).

Different size radio tags will be used to ensure that tags do not exceed 2% of the fish's body weight (Winter 1983). Model F1845 (26 grams total weight) will be used to mark fish 550mm (mid-eye to tail fork, MEF) or larger, and model F1840 (22 grams total weight) will be used to tag fish smaller than 550mm (MEF). Approximately 10% of the Kuskokwim River Chinook salmon are smaller than 550mm in length, based on data from a gillnet test fishery operated downriver from the tag site (Figure 6). To ensure that an adequate supply of small tags were available 20% (n=200) of the available tags will be Model F1840.

All healthy pre-spawn Chinook salmon larger than 450mm (MEF) will be tagged. Tagging will occur without anesthesia. Fish will be placed in a cradle suspended in a sampling tub filled with circulating river water. Radio tags will be inserted through the esophagus and into the upper stomach using a 30 cm plastic tube with a diameter less than that of the radio tags. The radio transmitter will be pushed through the esophagus such that the antenna end of the radio tag will be seated 0.5 cm beyond the posterior base of the pectoral fin. All radio tagged fish will also be marked externally with a uniquely numbered Floy model FD-68BC t-bar anchor tag. Tags will be placed approximately 1cm below and 2 fin rays anterior to the posterior insertion of the dorsal fin. Anchor tags will be brightly colored corresponding to location and gear of capture. Fish will be released near shore in calm water immediately after being tagged.

RECAPTURE METHODS

Weirs operated on the Salmon, George, Kogrukluk, and Tatlawiksuk Rivers will be used for recapture sampling (Figure 2). Weir operations will begin approximately June 15 and will continue until September 20. The dates of operations have been shown to encompass the entire Chinook salmon escapement at each of the 4 recovery locations (Clark and Blain 2012; Robbins and Blain 2012; Hansen and Blain 2013).

Each weir will be equipped with a passage chute and an integrated fish trap. A clear viewing window will be installed at the downstream end of the chute to aid in species identification and inspecting fish for external tags. The passage chute will be opened a minimum of 4 hours each day to allow salmon to pass the weir. All Chinook salmon will be visually identified and counted as they swim under the viewing window. A telemetry tracking station will be located just upstream of each weir site to record tag fish passing through the weir. Additionally, staff will attempt to capture and record external tag numbers from all tagged fish as they pass through the weir.

TRACKING EQUIPMENT AND METHODS

Stationary tracking will use a network of 17 ground-based towers (Figure 2). One tower will be located at Birch Tree Crossing, and will establish the lower boundary of the study area. One tower will be located approximately 40 kilometers downriver from the tag site to monitor fish that travel downriver after tagging. One tower will be located at each of the 4 recapture weir sites. The remaining 11 towers will be spaced approximately 50 river kilometers apart along the mainstem Kuskokwim River from Aniak (rkm 307) to Medfra (rkm 863). Those 11 towers will stratify the entire mainstem between Birch Tree Crossing and Medfra into 11 adjacent reaches useful for describing the upriver extent traveled by each tagged fish.

Each tower will include an ATS Model 4500 receiver that has an integrated data logger. Receivers will be powered by two, 12 V deep cycle batteries charged with a solar array. The receiver and batteries will be housed in a water-resistant steel box along with all associated components. Two four-element Yagi antennas will be mounted on a mast elevated 2-10 m above the ground. One antenna will be aimed upstream and the other downstream. The receiver will be programmed to receive from both antennas simultaneously and scan through the list of tag frequencies at 6 s intervals. When a signal of sufficient strength is encountered, the receiver will pause for up to 12 s on each antenna to decode and record tag information. The relatively short cycle period will help minimize the chance that a radio tagged fish will swim past the receiver site without being detected.

Two aerial survey flights will be flown along the mainstem Kuskokwim River between each ground-based tracking tower to determine if tagged fish remained in the mainstem or escaped into a spawning tributary. Ground-based tracking data will be used to determine the final mainstem reach for each tagged fish. If the fish was not located within that mainstem reach during aerial survey flights, then it will be assumed that the fish had moved into a spawning tributary that drained into that mainstem reach (Liller et al. 2011). Chinook salmon spawning has not been documented in the mainstem downriver of Medfra; therefore, all fish located in the mainstem will be assumed dead. One survey flight will be conducted immediately after tagging is completed in early August, and a follow up survey will be conducted within two weeks. Each survey is expected to take two days. Day one will be focused on surveying mainstem reaches, and day two will be focused on surveying all tributaries that drain a single mainstem reach. Limited tributary surveys are intended to ensure that the planned method results in the correct fate assignment.

Aerial tracking surveys will be conducted with a fixed wing aircraft, pilot, and surveyor who will operate a R4500 data logger. Scan time for each frequency will be 2 s. A single H-antenna will be mounted on each wing strut such that the antennas detect peak signals perpendicular to the direction of travel. Surveys will be flown at approximately 120 km/h at an altitude between 100 and 300 m above the center of the river. Once a tag is detected, the surveyor will prompt the data logger to record tag information.

VOLUNTEER TAG LOTTERY

A voluntary tag recovery lottery will be conducted to evaluate harvest mortality of tagged fish. Radio and anchor tags will be clearly labeled with contact information for reporting tagged fish that are harvested or found by the public. The lottery will be publicized pre-season using mailers and posters sent to rural businesses. A $200 monthly lottery will be held in June, July, and August, and a $500 grand prize drawing will be held in November. Each individual who voluntarily reports tag information will be entered in to the monthly lottery corresponding to the date the information was reported. At the end of the season all monthly entries will be pooled for the grand prize drawing.

DATA COLLECTION

Data collected at the tag site will be recorded using Allegro hand-held data computers. The following data will be collected for each sampling event: date, start time, end time, gear type, location, and crew. Non-target species will be counted and released immediately. All Chinook salmon will be measured to the nearest mm (MEF), and sex will be determined using visual observation of secondary sexual characteristics. The relative health of Chinook salmon will determined, by visually examining fish color and physical condition (e.g., external wounds), and recorded. All healthy Chinook salmon >450mm will be tagged. For each tagged fish, radio tag frequency and code will be recorded along with corresponding anchor tag color and number. During the first sampling event of each tagging shift, environmental data will be collected, including: cloud cover, wind direction, wind speed, water level, turbidity, and fish wheel depth. In addition a hobo temperature monitor will be attached to each fish wheel and will collect hourly water temperature. All data collected at the tag site will be downloaded to an Access database daily. Crew leader and project biologist will review data and consult with crews to rectify and correct data entry errors inseason

Data collected at recapture sites will be recorded on paper data forms. The time of each counting shift will be recorded as well as the total shift count of Chinook salmon observed passing upstream of the weir site. A separate data form will be filled out each day that a tagged fish is passed through the weir. Date and time of passage will be recorded. If the fish can be successfully captured in the weir trap, the following data will be collected: anchor tag number, presence/absence of radio tag, sex, and fish condition. Tag recovery data will be emailed to project leaders daily, and data discrepancies will be addressed inseason.

The total Chinook salmon passage at each site will be sampled for sex and length composition. This sampling will occur as a regular part of the stock assessment program (Liller et al. 2013) and will be used for testing mark–recapture assumptions. Sample information will be emailed to project leaders weekly.

Telemetry tracking data will be recorded using an ATS R4500 data logger. The data logger will record date, time, tag frequency, tag code, and signal strength for each radio tag fish within range. In addition, the data logger will record location when operated in aerial mode.

SAMPLE SIZE

Accuracy and precision of the abundance estimate is a function of the model selected, the population size, and sample sizes in each of the two events. We anticipate using a Petersen type estimator. The population size of Chinook salmon past the tag site is expected to be between 50,000–150,000, based on expectations of a below average total run (<250,000) and the existing whole river escapement goal of 65,000–120,000. Based on prior study years using similar methods, we expect to catch and tag approximately 500 Chinook salmon (Table 5). We anticipate up to 20% of tagged fish will be culled from the study due to capture induced mortality, traveling downriver after tagging, or leaving the study area. Given these expected parameters, we have calculated the number of Chinook salmon that must be counted past the recapture weirs in order to achieve the desired precision criteria (Table 6; Robson and Reiger 1964). Based on recent escapement estimates at the four weirs 2001–2012 (Table 7), it is likely that the number of Chinook salmon examined will exceed the minimum number necessary to achieve the precision criteria. Diagnostic testing of prior year results indicated that in 5 of the 6 years an unstratified model was appropriate to estimate abundance of Chinook salmon above Birch Tree Crossing (Table 8). However, if a full or partially stratified estimator is required, the precision criteria will likely not be met.

DATA ANALYSIS

The number of radio tagged fish that moved upstream of the tagging site (n_{rup}), and the total number of radio tagged fish released at the tag site (n_{rm}) will be used to estimate the proportion of tagged fish that entered the marked population (p_{up}), where $p_{up}=n_{rup}/n_{rm}$. The expected number of marked fish (M') will be estimated as $M{\cdot}p_{up}$.

Recapture samples collected at each of the 4 weir locations (C_i) will consist of all Chinook salmon observed passing upstream of weir i (i=1,…,4) during operable periods and all estimates of missed passage (C_{Ei}). The total recapture sample (C') will be estimated as $\sum(C_i + C_{Ei})$ Missed passage will be estimated by weir staff, and will be assumed to be without error.

The number of recaptures (R_i) for weir i (i=1,…,4) will consist of all radio tagged fish detected passing upstream of each weir using telemetry. The total number of recaptures ($\sum(R_i)$) will be adjusted to account for fish that shed their radio tag and cannot be detected by the stationary tracking tower. We assume that staff operating each weir will recognize all marked fish that swam through the weir, during operable periods, as long as the external anchor tag is still attached. We will use the total number of anchor tagged fish detected passing the weir sites by the weir staff (n_{rt}) and the total number of those fish detected using telemetry (n_r) to estimate the proportion of all fish that retained the radio tag (p_{rt}), where $p_{rt}=n_{rt}/n_r$. The expected number of recaptures (R') will be estimated as $\sum R_i/p_{rt}$.

Chapman's modification of the Petersen estimator (Chapman 1951; Seber 1982) will be used to estimate total abundance of coho salmon upstream of rkm 294,

$$\hat{N} = \frac{(M'+1)(C'+1)}{R'+1} - 1. \tag{1}$$

Variance Estimation

Variance of the mark-recapture estimates will be estimated with B=1,000 parametric bootstrap simulations (Efron 1982). Each uncertain parameter, M', p_{rt}, and R' associated with the tagging and recapturing processes will be modeled, denoted in subsequent equations with an asterisk (*). With each bootstrap replicate, denoted with subscript (b), a probable value for each parameter will be drawn from an assumed distribution and a bootstrap estimate of simulated abundance will be calculated using equation 1.

The number of tagged fish that moved upstream is assumed to have a binomial distribution (BN), and will be modeled as, $M^*_{(b)} \sim BN(M, p_{up})$.

The proportion of tagged fish out of all tagged fish released, p_i, will be separated into 5 classes (i=0,…,5): 1) entered marked population but moved to non-terminal area or harvested (p_0); 2) moved upstream of Salmon River weir (p_1); 3) moved upstream of George River weir (p_2), 4) moved upstream of Kogrukluk River weir (p_3), and 5) moved upstream of Tatlawiksuk River weir (p_4). The number of fish recovered at each weir site is assumed to have a multinomial distribution, and will be modeled as, $R^*_{(b),i} \sim multi(M^*_{(b)}, p_i)$.

The proportion of anchor tag retention will be modeled as a binomial process, $p^*_{(b)rt} \sim BN(n_r, p_{rt})/n_r$. The total number of fish recovered will then be modeled as, $R^*_{(b)} = (\sum R^*_{(b)i}) / p^*_{(b)rt}$.

The average bootstrap estimate of simulated abundance $\overline{N}^*_{(b)}$ calculated as $(\Sigma N^*_{(b)})/1{,}000$ will be used to approximate variance of the mark-recapture estimate, using the following equation:

$$v(\hat{N}) = \frac{\sum_{(b)} (N^*_{(b)} - \overline{N}^*_{(b)})^2}{B-1} \quad . \tag{2}$$

Alternate Abundance Model

Robust abundance estimates using the Petersen estimator is dependent on maintaining a uniform probability of marking among all spawning stocks during the first sampling event. Comparison of mark rates among recapture sites will provide evidence for homogeneous capture probability. If we find that capture probability is not equal or statistical power to perform hypothesis tests is insufficient due to lower than expected capture or recapture sampling, alternative models will be used.

Bromaghin et al. (2010) presented a likelihood framework for estimation of salmon abundance using telemetry data. This model permits capture probabilities and migratory timing to vary among temporal strata defined at the tag site. The flexibility of the model allows mark rates to vary among groups of fish passing the tag site. The estimation procedure assumes that catch per unit effort (CPUE) at the tag site is proportional to population abundance, and requires the following data:

1. CPUE collected from the tag site,
2. a determination of where individual tagged fish spawn, and
3. escapement counts from one or more spawning locations.

Our study design will ensure sufficient data is collected to implement the likelihood framework in the event that the Petersen estimator is determined to be inadequate. The distribution of stationary tracking towers (mainstem and tributary locations) will be used to stratify the mark–recapture study area into 15 spawning populations (*P*; Figure 7). For simplicity a spawning population refers to all fish bound for the same tributary or a group of tributaries and shares a similar migratory timing past the tag site. The entire migratory period past the Kalskag tag site will be stratified post season into *S* temporal strata, such that capture probabilities within each stratum are similar. Fish will be sampled from the aggregate of *P* populations as they pass the tag site, and n_j fish will be marked with a radio tag in the *j*th temporal stratum. Tagged fish will be monitored using stationary and aerial survey techniques as they migrate upriver and segregate into *P* spawning populations, such that n_{ij} of the n_j fish tagged during stratum *j* can be assigned to population P_i (i=1,…, 15). For the *i*th population, the proportion that is present and available for capture in the *j*th stratum is denoted π_{ij}; $\sum_j \pi_{ij} = 1$, assuming the entire migratory period is sampled. The total abundance of the *i*th population at the capture site is denoted N_i, and the abundance of *F* (*F*=1,…,4) of *P* populations will be known from escapement monitoring. The parameters of interest are the migratory timing parameters π_{ij} and the abundance of the 11 (*P*-*F*) unmonitored spawning populations.

Conditioning on data from 3 discrete phases of the experiment will yield estimates of the most likely parameter estimates for each population.

- Phase 1 evaluates the distribution of catches among temporal strata, conditioned on the number of fish captured ($C=\sum C_j$), where C_j is the number of fish captured in stratum j. The stratum effort E_j required to capture C_j fish is assumed to be proportional to total abundance. The likelihood function for this phase is given by the product of S multinomial distributions:

$$L_1 = C!\prod_{j=1}^{S}\left\{\left[\frac{1}{C_j!}\right]\left[\frac{E_j\sum_{i=1}^{P}N_1\pi_{ij}}{\sum_{k=1}^{S}\left(E_k\sum_{i=1}^{P}N_1\pi_{ij}\right)}\right]^{C_j}\right\}.$$

- Phase 2 evaluates the number of fish whose population identity was successfully determined (t_j) in stratum j, conditioned on n_j. The likelihood function for this phase is given by S binomial distributions:

$$L_2 = \prod_{j=1}^{S}\left[\binom{n_j}{t_j}\theta_j^{t_j}\left(1-\theta_j\right)^{n_j-t_j}\right],$$

  where Θ_j is the probability that the identity of a fish tagged in stratum j can be determined.

- Phase 3 evaluates the distribution of tagged fish among the 15 P populations, conditioned on t_j. The likelihood function for this phase is given by the product of S multinomial distribution:

$$L_3 = \prod_{j-1}^{S}\left\{t_y!\prod_{i=1}^{P}\left[\frac{1}{t_{ij}!}\left(\frac{N_i\pi_{ij}}{\sum_{k=1}^{P}N_k\pi_{kj}}\right)^{t_{ij}}\right]\right\}.$$

The likelihood function for the entire experiment is then given by: $L=L_1L_2L_3$.

SCHEDULE AND DELIVERABLES

All information from this project will be summarized in a Fisheries Data Series Report. Important project activities and the dates they will be conducted and completed are given below.

Date(s)	Project Activity
November, 2013–February, 2014	Recruit and hire vacant Fishery Biologist I
February, 2014	Recruit and hire vacant College Intern I
November, 2013–May, 2014	Procurement of project supplies
May 1–30	Recruit and hire local KNA field technician
May 1–16	Ship field supplies to Aniak, Sleetmute, and McGrath
May 17	Zachary Liller and FB I travel to Bethel and transport boat to Aniak
May 19–23	Zachary Liller and FB I install mainstem stationary tracking towers
May 26–30	Zachary Liller and FB I install tagging field camp
June 1	Tagging technicians and weir staff arrive in Aniak
June 2–4	Install fish wheels and conduct training
June 5–July 31	First event capture and tagging operations
June 5–June 14	Installation of weirs and tributary tracking towers
June 15–September 20	Second event recapture sampling
August 1–6	Winterize tagging camp and supplies
~August 7	First aerial survey flight
~August 21	Second aerial survey flight
September 21–October 1	Winterize weir camps and stationary tracking towers
October–February, 2015	Data analysis
March, 2015	Draft report to Area Biologist and Biometrician
May, 2015	Draft report to Regional Research Supervisor

RESPONSIBILITIES

Alaska Department of Fish and Game, Division of Commercial Fisheries

Kevin Schaberg, Fishery Biologist III. – Kuskokwim Area fishery biologist, provides general project oversight

Hamachan Hamazaki, Biometrician III. – Operational planning and data analysis support.

Zachary Liller, Fishery Biologist II. – Project leader, assists with field preparations, assists with data collection, assists with telemetry tracking, leads data analysis, author final reports, and oversees project budget and personnel.

Brittany Blain, Fishery Biologist II. – Weir project leader, oversees weir staff responsible for recapture sampling, conducts estimates of missed passage.

Jordan Head, Fishery Biologist I. – Tagging field crew leader, conducts field preparations, assists in sampling, maintains telemetry stations, conducts aerial surveys, and assists with data analysis and reporting.

Tracy Hansen, Fishery Biologist I. – Weir field crew leader, assists with recapture sampling and maintenance of telemetry stations.

Joshua Clark, Fishery Biologist I. – Weir field crew leader, assists with recapture sampling and maintenance of telemetry stations.

Rob Stewart, Fish and Wildlife Tech IV. – Weir consultant, assists with weir installation, assists with recapture sampling and maintenance of telemetry stations.

Cameron Lingnau, Fish and Wildlife Tech. II. – Operation of drift gillnets and fish wheels, tagging, assists with maintenance of telemetry stations.

Alex Nicori, Fish and Wildlife Tech. II. – Operation of drift gillnets and fish wheels, tagging, assists with maintenance of telemetry stations.

Vacant, College Intern II. – Operation of drift gillnets and fish wheels, tagging, assists with maintenance of telemetry stations.

Kuskokwim Native Association (Aniak)

Dan Gillikan, Fishery Director – Provides general field support, hires local Fishery Technician II for tagging operations.

Vacant, Fishery Tech. II. – Operation of drift gillnets and fish wheels, tagging, assists with maintenance of telemetry stations.

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TABLES AND FIGURES

Table 1.–Estimates of abundance for Chinook salmon upstream of Birch Tree Crossing, 2003–2007.

	Project Year				
	2003	2004	2005	2006	2007
Abundance from Stuby 2007	103,161 [a]	146,839 [a]	145,373 [a]	233,133 [b]	-
Abundance Estimate above Birch Tree Crossing	125,235	224,519	174,317	245,043	130,279
Lower 95% CI	83,679	136,933	121,499	163,722	91,483
Upper 95% CI	185,292	334,729	250,596	338,966	182,968
CV%	24%	26%	22%	21%	21%

Source: Schaberg et al. 2012

[a] Estimate from Stuby 2007. Estimate does not include Aniak River Chinook salmon (rkm >310).

[b] Estimate from Stuby 2007. Estimate includes Aniak River Chinook salmon. Estimate is from Aniak (rkm >307).

Table 2.–Daily fishing and shift schedule, 2014.

	Gear Type		Shift				
Time	Fish Wheel	Drift Gillnet	1	2	3	4	Crew Leader
0100	O	O					
0200	O	O					
0300	O	O					
0400	O	O					
0500	O	O					
0600	Start [a]	O	1	1			
0700	F	O					
0800	F	F	1	1			1
0900	F	F	1	1			1
1000	F	F	1	1			1
1100	Start [b]	O					1
1200	F	O					
1300	F	F	1		1	1	
1400	F	F	1		1	1	
1500	F	F	1		1	1	
1600	O	O					
1700	O	O					
1800	Start [b]	O			***1*** [c]		
1900	F	O				***1*** [c]	
2000	F	F		1	1	1	
2100	F	F		1	1	1	
2200	F	F		1	1	1	
2300	O	O					
2400	O	O					
Total Hours	12	4.5	7	7	7	7	4 [d]

Note: F = hours when gear is being fished, O = hours when gear is turned off or not fished. 1 = hours worked. Fishwheels will remain spinning 24 hours a day; however, the live box will be opened to allow fish to get out during non-fishing hours.

[a] Requires closing the live box and adjusting distance from the bank and vertical position of baskets.

[b] Requires closing the live box.

[c] Hours are reserved for equipment repair and associated fishing tasks (e.g., net mending, fuel, minor repairs).

[d] Crew leader will work an additional 3-4hr each day focused on data review, logistics, and administrative tasks.

Table 3.–Daily drift schedule, 2014.

		Station		
Day	Shift	1	2	3
1	1	8 (1)		
	2		7.5 (2)	
	3			8 (3)
2	1		8 (1)	
	2			7.5 (2)
	3	7.5 (3)		
3	1			8 (1)
	2	8 (2)		
	3		7.5 (3)	
4	1	7.5 (1)		
	2		8 (2)	
	3			7.5 (3)
5	1		7.5 (1)	
	2			8 (2)
	3	8 (3)		
6	1			7.5 (1)
	2	7.5 (2)		
	3		8 (3)	

Table 4.–Radio tag frequencies and codes used to tag and track Chinook salmon, 2014.

Purpose	Tag Model	Frequency	Codes
Large Chinook Tagging	F1845B	149.390	0-99
		149.410	0-99
		149.430	0-99
		149.450	0-99
		149.470	0-99
		149.490	0-99
		149.510	0-99
		149.530	0-99
Small Chinook Tagging	F1840B	149.550	0-99
		149.570	0-99
Reference Tag (Stationary Tracking)	F1860B	149.600	2-6, 11-24, 26

Table 5–Final fates of radiotagged Chinook salmon, 2002–2007 determined from aerial tracking, tracking stations, and weir recoveries.

Watershed/Tributary	Project Year					
	2002	2003	2004	2005	2006	2007
Total Tagged						
Fish wheel	187	239	123	215	210	140
Gillnet	274	249	258	234	296	203
Subtotal Tagged	461	488	381	449	506	343
Dropped Downstream of Tagging Site [a]	33	28	63	39	43	16
Tags Available for Recovery	428	460	318	410	463	327
Upriver Destinations						
Aniak River Subtotal	182	81	84	53	109	59
Mainstem [b]	154	53	62	41	82	38
Upper Aniak River [c]	15	11	8	5	8	8
Salmon River (R_1)	10	9	5	4	6	6
Kipchuk River	3	8	9	3	13	7
Oskawalik River	7	7	2	8	7	0
Holokuk River	3	5	10	7	3	11
Holitna River Subtotal	96	176	108	166	169	135
Lower Holitna River [d]	1	3	2	6	3	3
Upper Holitna River [e]	51	79	45	65	94	67
Hoholitna River	26	45	35	44	36	22
Kogrukluk River (R_3)	18	49	26	51	36	43
George River (R_2)	12	10	10	6	10	11
Stony River	3	7	7	23	38	18
Swift River	13	31	17	24	31	25
Tatlawiksuk River (R_4)	4	16	[f] 5	12	8	5
Takotna River (R_5)	1	6	1	2	1	6
Upstream of McGrath	22	32	7	17	22	12
Successful to Spawning Areas	343	371	251	318	398	282
Main Stem	85	89	67	92	65	45
Subtotal to Upriver Locations	428	460	318	410	463	327

Source: Schaberg et al. 2012

[a] Drop out tags are defined as those tags that did not enter the marked population upstream of Birch Tree Crossing.

[b] Mainstem Aniak is defined as the reaches of the Aniak River from the confluence with the Kuskokwim River to the confluence of the Kipchuk River.

[c] Upper Aniak is defined as the reaches of the Aniak River upstream of the Kipchuk River confluences.

[d] Lower Holitna River is defined as the reaches of the Holitna River from the confluence with the Kuskokwim River to the Hoholitna River confluence.

[e] Upper Holitna is defined as the reaches of the Holitna River upstream of the Hoholitna River confluence.

[f] Weir was not operational; tags identified with ground-based tacking station, recaptures not included in mark–recapture estimate.

Table 6.–Number of Chinook salmon needed to pass by the four recapture weirs to achieve objective criteria for precision for a range of expected population sizes.

Objective Criteria	Population Size [a]	Number Marked [b]	Number Required Past the Four Weirs
N±25%; α = 0.05	50,000	400	7,387
	75,000	400	11,106
	100,000	400	14,825
	125,000	400	18,544
	150,000	400	22,263

[a] Based on below average (<250,000) expected run and current escapement goal 65,000-120,000.

[b] Based on expectation of tagging 500 fish with 20% censored do to various reasons.

Table 7.–Total estimated escapement of Chinook salmon past the four recapture weir sites, 2002–2012.

	Year										
Location	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Salmon River Weir	-	-	-	-	6,731	2,376	-	-	-	-	768
George River Weir	2,444	4,692	5,206	3,845	4,355	4,883	2,698	3,663	1,500	1,571	2,302
Tatlawiksuk River Weir	2,237	1,680	2,833	2,918	1,700	2,061	1,071	1,071	569	1,014	1,116
Kogrukluk River Weir	10,105	11,771	19,651	21,999	19,414	13,034	9,730	9,701	5,693	6,890	1,156 [a]
Total	14,786	18,143	27,690	28,762	32,200	22,354	13,499	14,435	7,762	9,475	5,342
Average (2002-2012)	17,677										
Average (2010-2012)	7,526										

[a] The Kogrukluk River weir did not operate for a considerable portion of the 2012 season. Estimates of missed passage were not made. The number shown is the observed escapement.

Table 8.–Chinook salmon passage at weirs, associated radio tag recoveries and Chi-square results testing equal probability of tagging upriver spawning stocks, 2002–2007.

		Project Year																	
		2002			2003			2004			2005			2006			2007		
Recovery Site	Distance (rkm) [a]	Weir Passage	Recovered Tags		Weir Passage	Recovered Tags		Weir Passage	Recovered Tags		Weir Passage	Recovered Tags		Weir Passage	Recovered Tags		Weir Passage	Recovered Tags	
			Number	Ratio		Number	Ratio		Number	Ratio		Number	Ratio		Number	Ratio		Number	Ratio
Salmon	404	-- [b]	--		-- [b]	--		-- [b]	--		-- [b]	--		6,732	9	0.0013	6,220	8	0.0013
George	453	2,444	12	0.0049	4,693	10	0.0021	5,207	9	0.0017	3,845	6	0.0016	4,357	9	0.0021	4,883	10	0.0020
Tatlawiksuk	568	2,237	4	0.0018	-- [b]	--		2,833	5	0.0018	2,920	12	0.0041	1,700	7	0.0041	2,061	5	0.0024
Kogrukluk	718	10,104	18	0.0018	11,771	49	0.0042	19,651	24	0.0012	22,000	49	0.0022	19,414	36	0.0019	13,029	43	0.0033
Takotna	835	316	0	0.0000	378	2	0.0053	461	1	0.0022	499	1	0.0020	539	0	0.0000	418	0	0.0000
Total		15,101	34	0.0023	16,842	61	0.0036	28,152	39	0.0014	29,264	68	0.0023	32,742	61	0.0019	26,611	66	0.0025
Chi Square Results:																			
p-value [c]			0.0230			0.2513			0.7246			0.1680			0.1522			0.0756	
H_o Decision [d]			Fail to Reject			Fail to Reject			Fail to Reject			Fail to Reject			Fail to Reject			Fail to Reject	

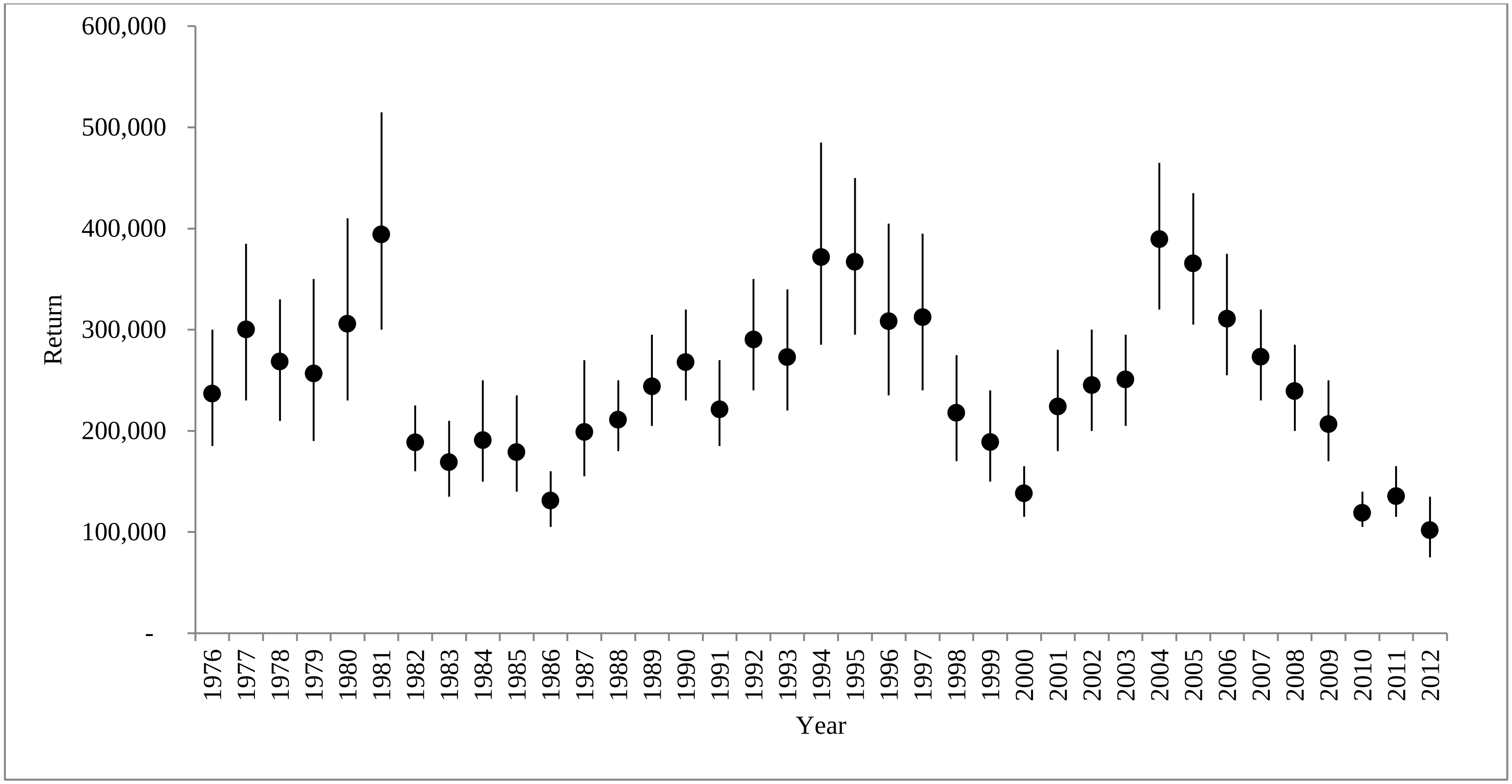
Source: Schaberg et al. 2012

[a] Distance in river kilometers (rkm) from the mouth of the Kuskokwim River.

[b] Weir not operational.

[c] α=0.05

[d] H_o = no difference in probability of tagging between stocks.



Source: Modified from Bue et al. 2012.

Figure 1.–Reconstructed estimates of total annual return of Kuskokwim River Chinook salmon (95% credible intervals), 1976–2012.

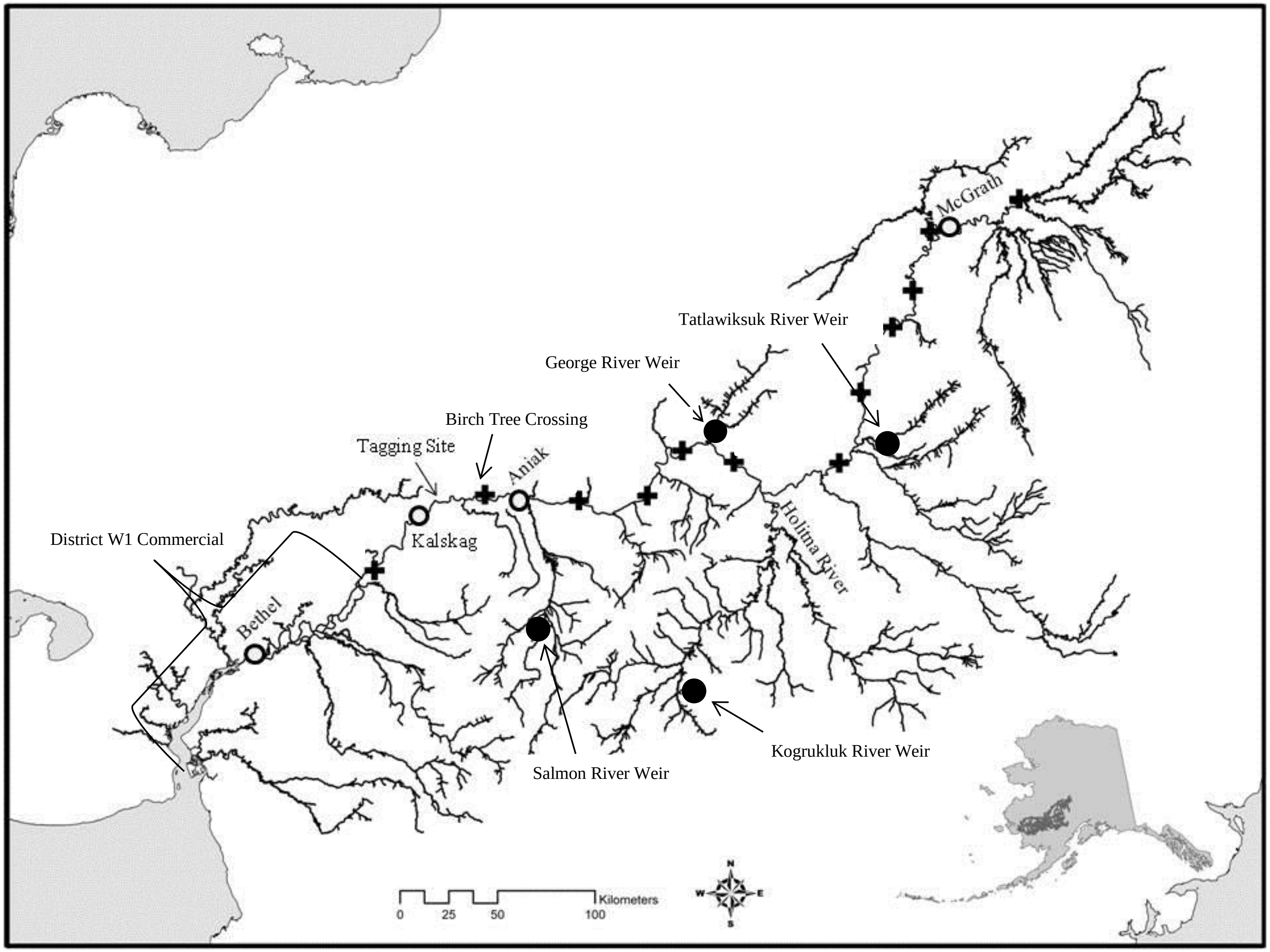


Figure 2.–Approximate location of the tag site, recapture sites (circles), potential mainstem tracking stations (crosses), and District W1 commercial harvest area.

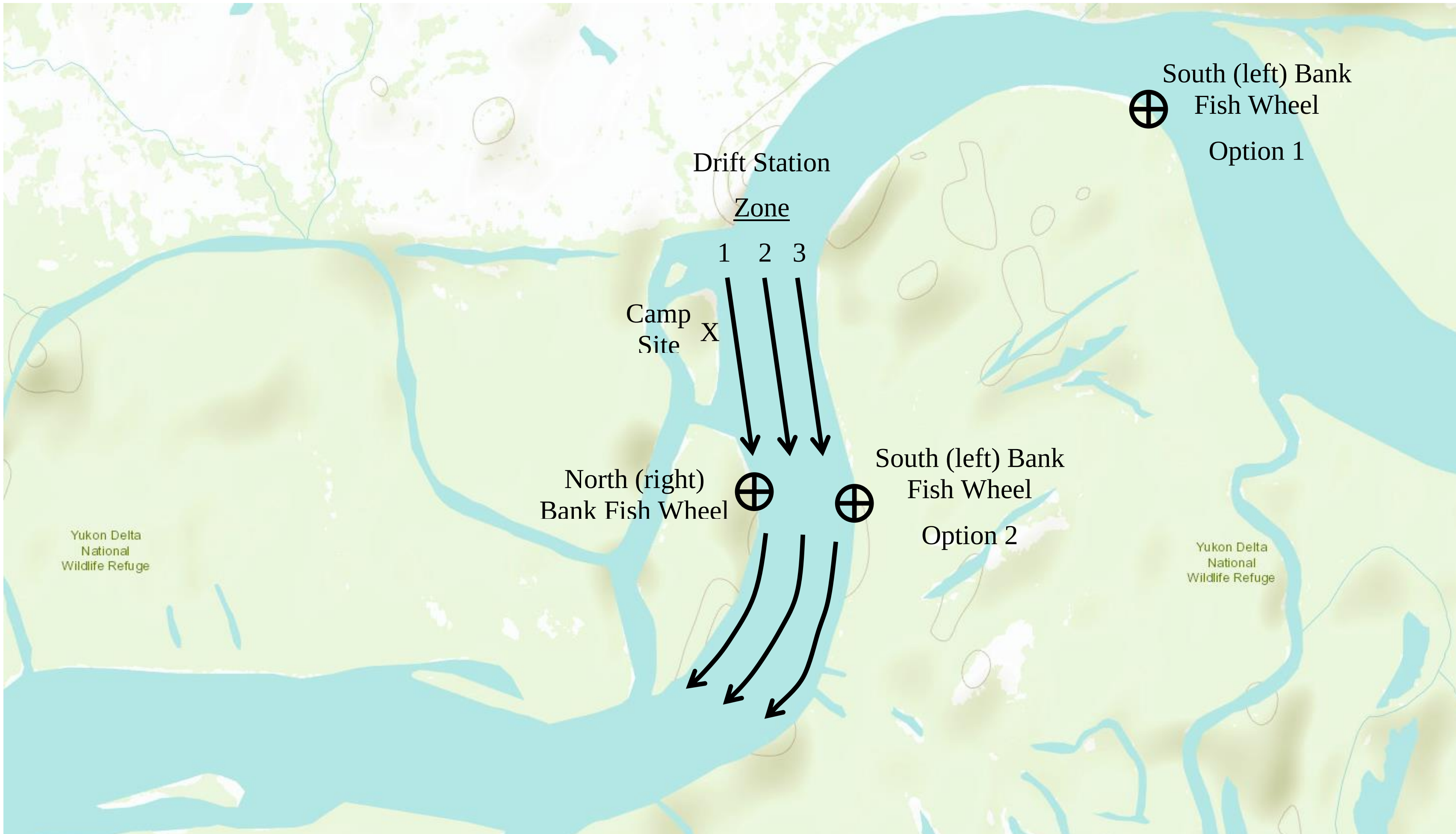


Figure 3.–Approximate locations of bank-mounted fish wheels and drift sites used in 2014.

Note: Location of the south bank wheel will be determined inseason, based on river bottom profile, water depth, and velocity at each of the 2 potential sites.

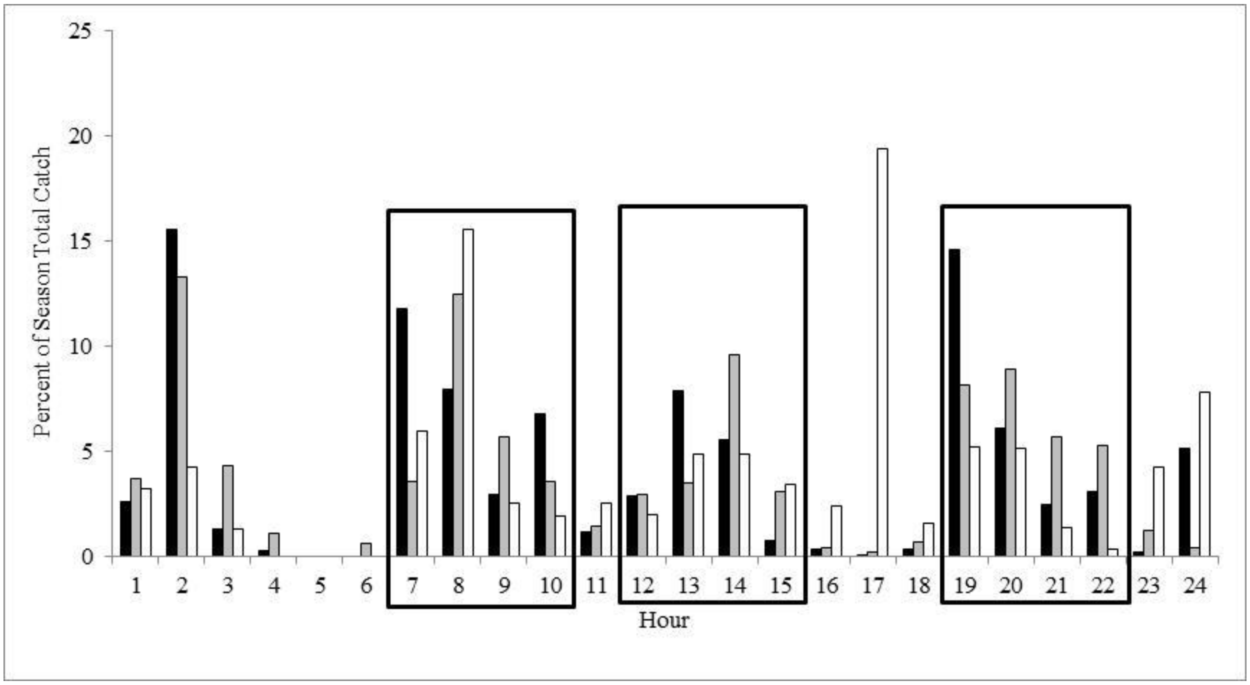


Figure 4.–Percent of season total catch of Chinook salmon during each hour of fish wheel operation at the Kalskag (rkm 270) tag site in 2003 (black bars), 2005 (grey bars), and 2006 (open bars).

Note: Fish wheels were located at river kilometer 270, operated 24 hours each day and fishing effort was assumed similar over time. Other year data were not used because tag site was different (2004) or wheels were only operated during a portion of each day (2007). Gillnet data was not used because nets were only fished for a portion of each day.

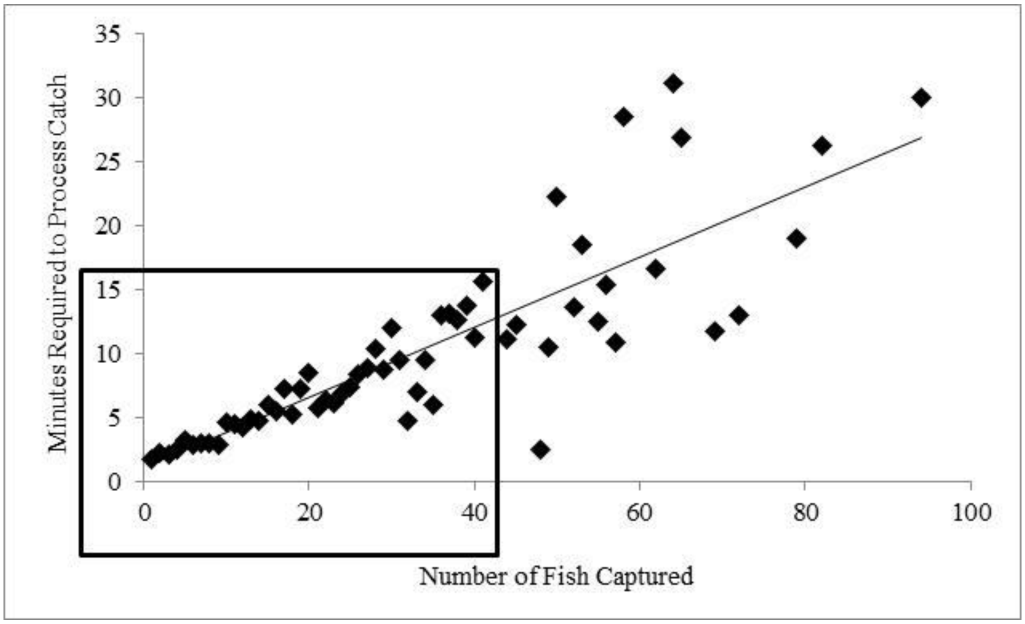


Figure 5.–Relationship between the total number of fish captured (all species) in one hour using fish wheels operated near Kalskag (rkm 270) and the time required to process captured fish, 2010.

Note: In 2010 target species was sockeye salmon (*O. nerka*); however, the tagging methods using in 2010 are the same as those planned for 2014. (e.g., 1hr holding time, esophageal radio tags, t-bar anchor tags, and basic data collection) and fish wheel catches of sockeye salmon are similar to Chinook salmon. During 2010, 96% of the hourly fish wheel checks contained 40 or fewer fish (all species combined). The average time required to process 40 fish was 11.5 minutes.

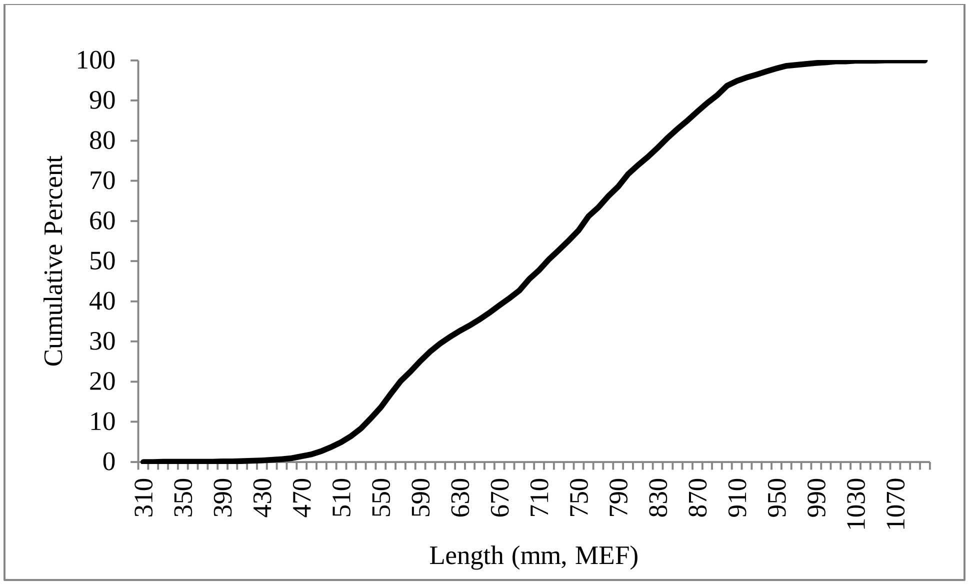


Figure 6.–Cumulative distribution of Chinook salmon length harvested in the Bethel Test Fishery 1981—2012.

Note: Bethel Test Fishery is located downriver of the 2014 tag site. Harvest occurs using drift gillnets with a stretch mesh size of 5 4 in and 8.0 in.

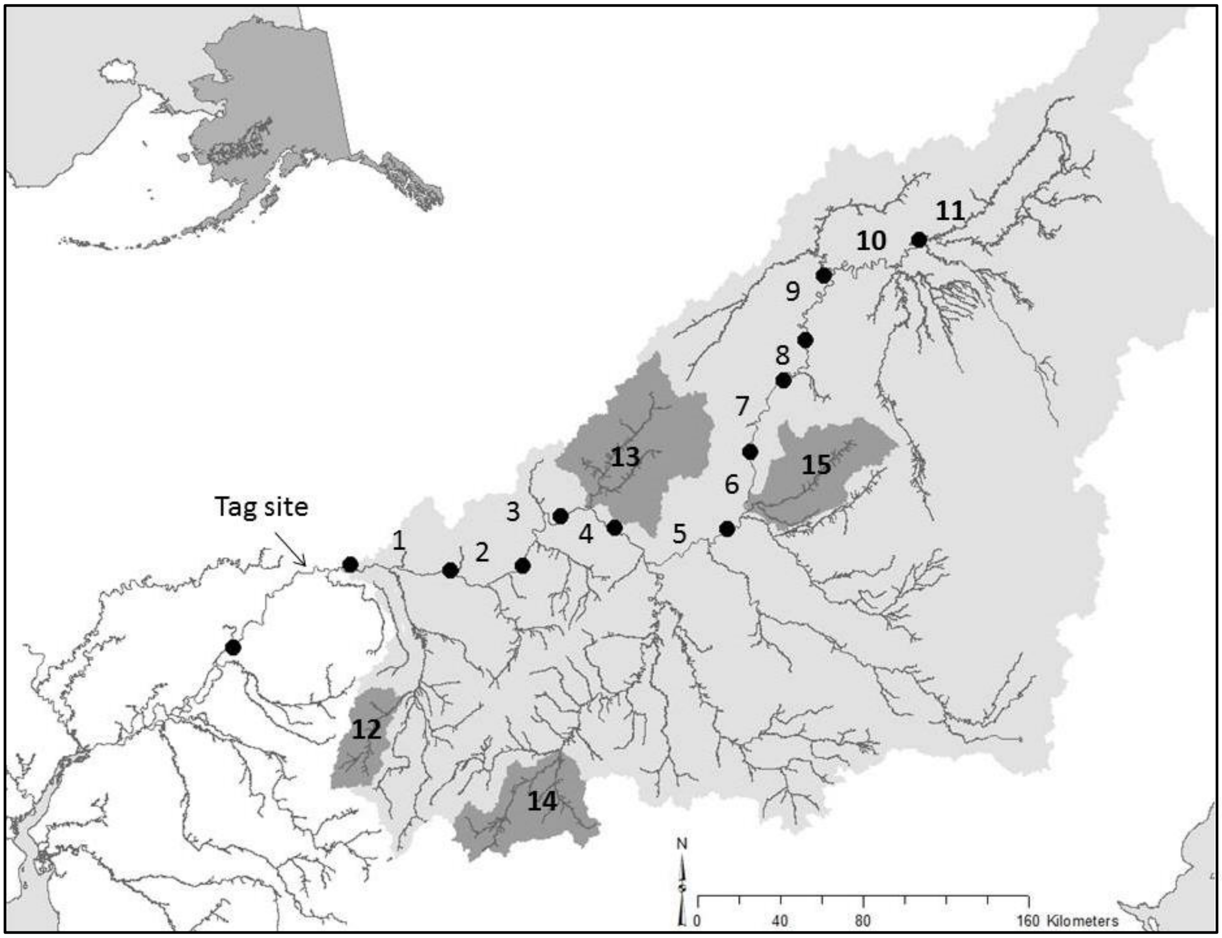


Figure 7.– Geographic stratification used to describe spawning populations throughout the study area.

Note: Telemetry towers and weirs are used to stratify the mark–recapture study area (shaded) into 15 spawning populations. Telemetry towers (black dots) stratify the mainstem Kuskokwim River into 11 spawning populations, which include all unmonitored tributaries (light gray) that drain into each mainstem section. Weirs are used to monitor Chinook salmon escapement for 4 spawning populations (dark grey).

APPENDIX A: STATISTICAL TESTS FOR ANALYZING DATA FOR SEX AND SIZE BIAS

Appendix A1.–Tests of consistency for the Petersen estimator.

The following conditions are critical assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during the first event; or,
3. Every fish has an equal probability of being captured and examined during the second event.

To evaluate these three assumptions, the chi-square statistic is used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952 as cited in Seber 1982; Chapman 1951) to be valid. If all three tests are rejected, the Petersen estimator is not appropriate.

I.-Test For Complete Mixing[a]

Area/Time Where Marked	Area/Time Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	$(n_1\text{-}m_2)$
1					
2					
…					
S					

II.-Test For Equal Probability of Capture During the First Event[b]

	Area/Time Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked $(n_2\text{-}m_2)$				

III.-Test For Equal Probability of Capture During the Second Event[c]

	Area/Time Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured $(n_1\text{-}m_2)$				

[a] This tests the hypothesis that movement probabilities (θ) from area or time i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among area or time designations: H_0: $\Sigma_i a_i \theta_{ij} = k U_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among area or time designations: H0: Σjθijpj = d, where pj is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix A2.–Detection of size and/or sex selective sampling (modified from Stuby 2007).

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) was used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R) by using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of (R). A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (Chi^2-test) was used to detect significant evidence that sex selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample.

Tests involving all of the fish examined during the second event (*C*) were modified to account for the fact that the age, sex and length (ASL) composition of the fish examined for marks during the second event was estimated and the number of samples collected at each site was not proportional to abundance. We approached this problem using a bootstrap resampling design (Efron 1982) to obtain representative samples from each weir project. It was assumed that the ASL samples from each weir were representative of the fish that passed through the weir, that a random sample of these ASL observations would represent a random sample of the weir population, and combining random samples from all weir projects would represent the total escapement. The test for differences in sex composition or length distribution for a year was then made by randomly selecting with replacement, ASL_i samples from those collected at weir *i*, combining them into a composite group composed of samples from all weirs examined that year and then calculating the test statistic. The random selection and the calculation of the test statistic was repeated 10,000 times and the expected value or mean of the 10,000 bootstraps was used to estimate the probability of failing to reject the hypothesis of no difference between the groups (p-value). The number of ASL observations to be included in the bootstrap sample from each weir was proportional to each river's escapement size. For each river where ASL samples were taken, a proportion of samples taken from escapement ($p_{s,i}$ = the number of ASL samples/escapement counts) were calculated, and the minimum sampling proportion ($p_{s,min}$) was used to determine escapement adjusted sample size as:

$$ASL_i = p_{s,\min} C_i \tag{1}$$

where C_i the number of fish estimated to have passed through weir *i* (i.e., escapement) and ASL_i is the adjusted bootstrap number of samples. The total number of ASL bootstrap samples (ASL_{Tot}) was the sum of the determinations;

$$ASL_{Tot} = \sum ASL_i \quad . \tag{2}$$

Interpretation:

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o

There is no size/sex selectivity detected during either sampling event. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II:

Reject H_o	Fail to reject H_o	Reject H_o

There is no size/sex selectivity detected during the first event but there is during the second event sampling. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification.

-continued-

Case III:

Fail to reject H_o Reject H_o Reject H_o

There is no size/sex selectivity detected during the second event but there is during the first event sampling. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification.

Case IV:

Reject H_o Reject H_o Either result possible

There is size/sex selectivity detected during both the first and second sampling events. Data must be stratified in order to eliminate variability in capture probability within strata for at least one or both sampling events.

Case V:

Fail to reject H_o Fail to reject H_o Reject H_o

Further evaluation of sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

APPENDIX B: HISTORICAL DAILY AND CUMULATIVE CATCHES OF CHINOOK SALMON AT THE KALSKAG CAPTURE SITE (RKM 270) USING DRIFT GILLNETS AND BANK-MOUNTED FISH WHEELS, 2002–2007

Appendix B1. Historical daily and cumulative catches of Chinook salmon at the Kalskag capture site (rkm 270) using drift gillnets and bank-mounted fish wheels, 2002–2007.

	Year											
	2002		2003		2004		2005		2006		2007	
Date	Num.	%	Num.	%	Num.	%	Num.	%	Num.	%	Num.	%
1-Jun	-	-	-	-	-	-	2	0	0	0	-	-
2-Jun	-	-	-	-	-	-	5	0	0	0	-	-
3-Jun	-	-	-	-	-	-	13	1	0	0	-	-
4-Jun	-	-	-	-	-	-	17	1	0	0	-	-
5-Jun	-	-	0	0	-	-	26	2	0	0	-	-
6-Jun	-	-	8	1	-	-	45	4	0	0	-	-
7-Jun	-	-	18	2	12	1	58	5	3	0	-	-
8-Jun	-	-	36	3	29	3	70	6	4	0	-	-
9-Jun	-	-	46	4	45	4	86	7	8	1	-	-
10-Jun	-	-	52	5	58	6	100	8	9	1	-	-
11-Jun	-	-	54	5	75	7	123	10	17	1	1	0
12-Jun	-	-	55	5	92	9	148	12	22	2	1	0
13-Jun	-	-	61	6	124	12	171	14	26	2	1	0
14-Jun	-	-	77	7	169	17	192	16	28	2	1	0
15-Jun	-	-	94	9	237	23	235	19	32	2	2	0
16-Jun	-	-	123	12	280	27	276	23	39	3	3	0
17-Jun	-	-	141	14	331	32	317	26	41	3	3	0
18-Jun	11	1	159	15	391	38	367	30	51	4	4	1
19-Jun	18	2	227	22	445	44	444	37	64	5	18	3
20-Jun	58	7	258	25	473	46	529	44	82	6	36	6
21-Jun	83	11	285	27	494	48	599	49	105	8	66	11
22-Jun	120	15	305	29	516	51	638	53	127	10	76	12
23-Jun	175	22	361	35	543	53	669	55	145	11	110	18
24-Jun	229	29	406	39	581	57	715	59	213	16	143	23
25-Jun	282	36	458	44	603	59	740	61	332	25	189	30
26-Jun	312	40	514	49	629	62	764	63	441	34	225	36
27-Jun	329	42	566	54	696	68	775	64	530	40	262	42
28-Jun	346	44	585	56	746	73	797	66	618	47	296	47
29-Jun	359	46	638	61	766	75	809	67	679	52	302	48
30-Jun	378	48	712	68	771	76	829	68	719	55	345	55
1-Jul	413	52	757	73	780	77	853	70	761	58	366	58
2-Jul	451	57	807	77	785	77	877	72	825	63	405	65
3-Jul	474	60	857	82	794	78	906	75	878	67	438	70
4-Jul	507	64	887	85	798	78	933	77	914	70	466	74
5-Jul	518	66	907	87	800	79	954	79	955	73	474	76
6-Jul	532	68	907	87	805	79	970	80	990	76	486	78
7-Jul	554	70	908	87	809	79	989	82	1010	77	506	81
8-Jul	570	72	908	87	811	80	1004	83	1032	79	518	83
9-Jul	589	75	908	87	812	80	1013	84	1049	80	533	85
10-Jul	608	77	911	87	816	80	1026	85	1071	82	546	87

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Appendix B1.–Page 2 of 2.

	Year											
	2002		2003		2004		2005		2006		2007	
Date	Num.	%	Num.	%	Num.	%	Num.	%	Num.	%	Num.	%
11-Jul	617	78	918	88	817	80	1043	86	1086	83	560	89
12-Jul	627	80	930	89	819	80	1050	87	1098	84	561	90
13-Jul	636	81	940	90	821	81	1062	88	1115	85	565	90
14-Jul	644	82	951	91	824	81	1069	88	1135	87	575	92
15-Jul	646	82	958	92	829	81	1075	89	1155	88	579	92
16-Jul	652	83	964	92	849	83	1082	89	1168	89	585	93
17-Jul	655	83	974	93	852	84	1088	90	1183	90	593	95
18-Jul	656	83	981	94	866	85	1092	90	1199	92	601	96
19-Jul	664	84	985	94	879	86	1093	90	1211	92	604	96
20-Jul	675	86	987	95	885	87	1097	91	1215	93	605	97
21-Jul	680	86	993	95	887	87	1100	91	1223	93	609	97
22-Jul	684	87	994	95	888	87	1105	91	1235	94	611	98
23-Jul	694	88	994	95	891	87	1105	91	1241	95	613	98
24-Jul	698	89	996	95	894	88	1112	92	1252	96	614	98
25-Jul	705	89	997	96	898	88	1115	92	1261	96	615	98
26-Jul	712	90	1001	96	903	89	1116	92	1265	97	616	98
27-Jul	717	91	1005	96	912	89	1118	92	1269	97	616	98
28-Jul	724	92	1007	97	917	90	1121	93	1273	97	616	98
29-Jul	732	93	1011	97	922	90	1129	93	1275	97	618	99
30-Jul	736	93	1012	97	924	91	1133	94	1279	98	620	99
31-Jul	738	94	1012	97	932	91	1136	94	1283	98	623	100

Note: Capture location was near river kilometer 270 in all years except 2004 when it was located at rkm 249. Two fish wheels were operated in all years except 2005, when three wheels were used. Fish wheels operated 24hr each day 7 days a week except 2007, when wheels operated 15hr each day 6 days a week. Approximately 3.0hr of drift gillnet effort was expended each day.